CALCIUM CHANNEL BLOCKERS COMPRISING TWO BENZHYDRIL MOIETIES

Cross-Reference to Related Applications

[0001] This application is a continuation-in-part of U.S. Serial No. 10/409,763 filed 8 April 2003, which is a continuation-in-part of U.S. Serial No. 10/060,900 filed 29 January 2002, which is a continuation of U.S. Serial No. 09/476,927 filed 30 December 1999, now U.S. patent 6,387,897; which is a continuation-in-part of U.S. Serial No. 09/401,699, filed 23 September 1999, now U.S. patent 6,294,533; which is a continuation-in-part of U.S. Serial No. 09/107,037 filed 30 June 1998, now U.S. patent 6,011,035. The contents of these applications are incorporated herein by reference.

Technical Field

[0002] The invention relates to compounds useful in treating conditions associated with abnormal calcium channel function. More specifically, the invention concerns compounds containing substituted or unsubstituted derivatives of 6-membered heterocyclic moieties that are useful in treatment of conditions such as stroke and pain.

Background Art

[0003] PCT publication WO 01/45709 published 28 June 2001 discloses calcium channel blockers where a piperidine or piperazine ring links a benzhydril moiety to an additional aromatic moiety or benzhydril. This publication, which is based on parent application 09/476,927, discussed above, is incorporated herein by reference. As explained in these applications, native calcium channels have been classified by their electrophysiological and pharmacological properties as T, L, N, P and Q types. T-type (or low voltage-activated) channels describe a broad class of molecules that transiently activate at negative potentials and are highly sensitive to changes in resting potential. The L, N, P and Q-type channels activate at more positive potentials (high voltage activated) and display diverse kinetics and voltage-dependent properties. There is some overlap in biophysical properties of the high voltage-activated channels, consequently pharmacological profiles are useful to further distinguish them. Whether the Q- and P-type channels are distinct molecular entities is controversial. Several types of calcium conductances do not fall neatly into any of the above

categories and there is variability of properties even within a category suggesting that additional calcium channels subtypes remain to be classified.

[0004] Biochemical analyses show that neuronal high voltage activated calcium channels are heterooligomeric complexes consisting of three distinct subunits (α_1, $\alpha_2\delta$ and β). The α_1 subunit is the major pore-forming subunit and contains the voltage sensor and binding sites for calcium channel antagonists. The mainly extracellular α_2 is disulfide-linked to the transmembrane δ subunit and both are derived from the same gene and are proteolytically cleaved *in vivo*. The β subunit is a nonglycosylated, hydrophilic protein with a high affinity of binding to a cytoplasmic region of the α_1 subunit. A fourth subunit, γ, is unique to L-type calcium channels expressed in skeletal muscle T-tubules.

[0005] Recently, each of these α_1 subtypes has been cloned and expressed, thus permitting more extensive pharmacological studies. These channels have been designated α_{1A}-α_{1I} and α_{1S} and correlated with the subtypes set forth above. α_{1A} channels are of the P/Q type; α_{1B} represents N; α_{1C}, α'_{1D}, α_{1F} and α_{1S} represent L; α_{1E} represents a novel type of calcium conductance, and α_{1G}-α_{1I} represent members of the T-type family.

[0006] Further details concerning the function of N-type channels, which are mainly localized to neurons, have been disclosed, for example, in U.S. Patent No. 5,623,051, the disclosure of which is incorporated herein by reference. As described, N-type channels possess a site for binding syntaxin, a protein anchored in the presynaptic membrane. Blocking this interaction also blocks the presynaptic response to calcium influx. Thus, compounds that block the interaction between syntaxin and this binding site would be useful in neural protection and analgesia. Such compounds have the added advantage of enhanced specificity for presynaptic calcium channel effects.

[0007] U.S. Patent No. 5,646,149 describes calcium channel antagonists of the formula A-Y-B wherein B contains a piperazine or piperidine ring directly linked to Y. An essential component of these molecules is represented by A, which must be an antioxidant; the piperazine or piperidine itself is said to be important. The exemplified compounds contain a benzhydril substituent, based on known calcium channel blockers (see below). In some cases, the antioxidant can be a phenyl group containing methoxy and/or hydroxyl substituents. In most of the illustrative compounds, however, a benzhydril moiety is coupled to the heterocycle simply through a CH group or C= group. In the few compounds where there is an alkylene chain between the CH to which the two phenyl groups are bound and the heterocycle, the antioxidant

must be coupled to the heterocycle through an unsubstituted alkylene and in most of these cases the antioxidant is a bicyclic system. Where the antioxidant can simply be a phenyl moiety coupled through an alkynylene, the linker from the heterocycle to the phenyl moieties contains no more than six atoms in the chain. U.S. Patent No. 5,703,071 discloses compounds said to be useful in treating ischemic diseases. A mandatory portion of the molecule is a tropolone residue; among the substituents permitted are piperazine derivatives, including their benzhydril derivatives. U.S. Patent No. 5,428,038 discloses compounds which are said to exert a neural protective and antiallergic effect. These compounds are coumarin derivatives which may include derivatives of piperazine and other six-membered heterocycles. A permitted substituent on the heterocycle is diphenylhydroxymethyl. Thus, approaches in the art for various indications which may involve calcium channel blocking activity have employed compounds which incidentally contain piperidine or piperazine moieties substituted with benzhydril but mandate additional substituents to maintain functionality.

[0008] Certain compounds containing both benzhydril moieties and piperidine or piperazine are known to be calcium channel antagonists and neuroleptic drugs. For example, Gould, R.J., *et al., Proc Natl Acad Sci USA* (1983) 80:5122-5125 describes antischizophrenic neuroleptic drugs such as lidoflazine, fluspirilene, pimozide, clopimozide, and penfluridol. It has also been shown that fluspirilene binds to sites on L-type calcium channels (King, V.K. *et al., J Biol Chem* (1989) 264:5633-5641) as well as blocking N-type calcium current (Grantham, C.J., *et al., Brit J Pharmacol* (1944) 111:483-488). In addition, Lomerizine, as developed by Kanebo KK, is a known calcium channel blocker; Lomerizine is, however, not specific for N-type channels. A review of publications concerning Lomerizine is found in Dooley, D., *Current Opinion in CPNS Investigational Drugs* (1999) 1:116-125.

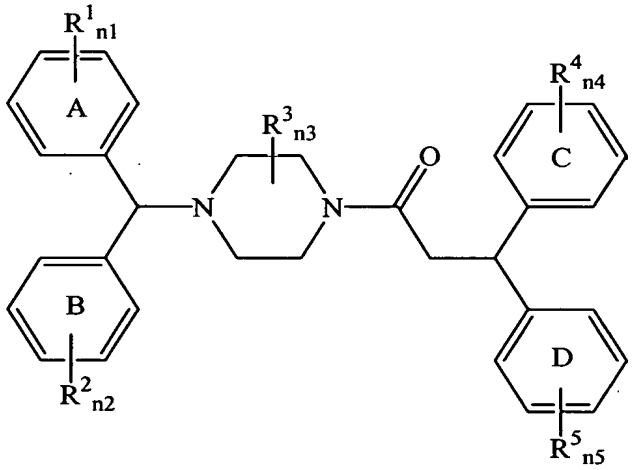
[0009] In addition, benzhydril derivatives of piperidine and piperazine are described in PCT publication WO 00/01375 published 13 January 2000 and incorporated herein by reference. This PCT publication corresponds to parent application 09/401,699 set forth above. Reference to this type of compound as known in the prior art is also made in WO 00/18402 published 6 April 2000 and in Chiarini, A., *et al., Bioorganic and Medicinal Chemistry*, (1996) 4:1629-1635.

[0010] Various other piperidine or piperazine derivatives containing aryl substituents linked through nonaromatic linkers are described as calcium channel blockers in U.S. 5,292,726; WO 99/43658; Breitenbucher, J.G., *et al., Tat Lett* (1998) 39:1295-1298.

[0011] The present invention is based on the recognition that the combination of a six-membered heterocyclic ring containing at least one nitrogen said nitrogen coupled through a linker to a benzhydril moiety results in effective calcium channel blocking activity. In some cases enhanced specificity for N-type and/or T-type channels, or decreased specificity for L-type channels is shown. The compounds are useful for treating stroke and pain and other calcium channel-associated disorders, as further described below. By focusing on these moieties, compounds useful in treating indications associated with calcium channel activity are prepared.

Disclosure of the Invention

[0012] The invention relates to compounds useful in treating conditions such as stroke, head trauma, migraine, chronic, neuropathic and acute pain, epilepsy, hypertension, cardiac arrhythmias, and other indications associated with calcium metabolism, including synaptic calcium channel-mediated functions. The compounds of the invention are benzhydril derivatives of piperazine with substituents that enhance the calcium channel blocking activity of the compounds. Thus, in one aspect, the invention is directed to compounds of the formula



(1)

wherein each R^1-R^5 is independently optionally substituted alkyl (1-10C), alkenyl (2-10C), alkynyl (2-10C), aryl (6-10C), arylalkyl (7-16C) or arylalkenyl (7-16C) each optionally further containing 1-4 heteroatoms (N, O or S) and wherein said optional substituents may include =O thus including embodiments wherein R^1-R^5 may independently form an acyl, amide, or ester linkage with the ring carbon to which it is bound, or each of R^1-R^5 is independently halo, CF_3, OCF, NO_2, NR_2, OR, SR, COOR, or $CONR_2$, wherein R is H or optionally substituted alkyl, alkenyl, alkynyl, aryl, arylalkyl, or arylalkenyl, as described above, and wherein two substituents at adjacent positions on the same ring may form a 3-7 membered

saturated or unsaturated ring fused to said substituted ring, said fused ring optionally itself substituted and optionally containing one or more heteroatoms (N, S, O), and R^3 may be keto if $n^3 = 1$;

or wherein a combination of R^1 and R^2 and/or R^4 and R^5 may form a bond or a bridge between phenyl groups A and B and/or C and D -*e.g.,* each of R^1 and R^2 or R^4 and R^5 together may be a bond or a single CR_2 group, an NR group, an O, or S wherein the S is optionally oxidized; and

wherein each n^1-n^5 is independently 0-4, with the proviso that at least one of n^1-n^5 must be other than 0.

[0013] The invention is also directed to methods to modulate calcium channel activity, preferably N-type and/or T-type channel activity, using the compounds of formula (1) and thus to treat certain undesirable physiological conditions; these conditions are associated with abnormal calcium channel activity. In another aspect, the invention is directed to pharmaceutical compositions containing these compounds, and to the use of these compounds for the preparation of medicaments for the treatment of conditions requiring modulation of calcium channel activity.

Brief Description of the Drawings

[0014] Figure 1 shows illustrative compounds of the invention.

[0015] Figure 2 is a graph showing the selectivity of compound P1 for N-, P/Q- and L-type channels.

[0016] Figure 3 is a graph showing the selectivity of compound P3 for N-, P/Q- and L-type channels.

[0017] Figure 4 is a graph showing the selectivity of compound P4 for N-, P/Q- and L-type channels.

[0018] Figure 5 is a graph showing the selectivity of compound P5 for N-, P/Q- and L-type channels.

[0019] Figure 6 is a graph showing the selectivity of compound P6 for N-, P/Q- and L-type channels.

[0020] Figure 7 is a graph showing the selectivity of compound P8 for N-, P/Q- and L-type channels.

Modes of Carrying out the Invention

[0021] The compounds of formula (1) useful in the methods of the invention exert their desirable effects through their ability to modulate the activity of N-type and/or T-type calcium channels. This makes them useful for treatment of certain conditions. Among such conditions where antagonist activity is desired are stroke, epilepsy, head trauma, migraine, inflammatory bowel disease and chronic, neuropathic and acute pain. Calcium flux is also implicated in other neurological disorders such as schizophrenia, anxiety, depression, other psychoses, and neural degenerative disorders. Other treatable conditions include cardiovascular conditions such as hypertension and cardiac arrhythmias. In addition, T-type calcium channels have been implicated in certain types of cancer, diabetes, infertility and sexual dysfunction.

[0022] While the compounds of formula (1) generally have this activity, availability of this class of calcium channel modulators permits a nuanced selection of compounds for particular disorders. The availability of this class of compounds provides not only a genus of general utility in indications that are affected by excessive calcium channel activity, but also provides a large number of compounds which can be mined and manipulated for specific interaction with particular forms of calcium channels. The availability of recombinantly produced calcium channels of the α_{1A}-α_{1I} and α_{1S} types set forth above, facilitates this selection process. Dubel, S.J., *et al., Proc Natl Acad Sci USA* (1992) 89:5058-5062; Fujita, Y., *et al., Neuron* (1993) 10:585-598; Mikami, A., *et al., Nature* (1989) 340:230-233; Mori, Y., *et al., Nature* (1991) 350:398-402; Snutch, T.P., *et al., Neuron* (1991) 7:45-57; Soong, T.W., *et al., Science* (1993) 260:1133-1136; Tomlinson, W.J., *et al., Neuropharmacology* (1993) 32:1117-1126; Williams, M.E., *et al., Neuron* (1992) 8:71-84; Williams, M.E., *et al., Science* (1992) 257:389-395; Perez-Reyes, *et al., Nature* (1998) 391:896-900; Cribbs, L.L., *et al., Circulation Research* (1998) 83:103-109; Lee, J.H., *et al., Journal of Neuroscience* (1999) 19:1912-1921.

[0023] It is known that calcium channel activity is involved in a multiplicity of disorders, and particular types of channels are associated with particular conditions. The association of N-type channels in conditions associated with neural transmission would indicate that compounds of the invention which target N-type receptors are most useful in these conditions. Illustrative conditions are:

- Chronic pain
  - Neuropathic pain
    - Diabetic peripheral neuropathy
    - Post-herpetic neuralgia
    - Trigeminal neuralgia
    - AIDS related neuropathy
  - Cancer pain
  - Inflammatory pain
    - Osteoarthritis pain
    - Rheumatoid arthritis pain
    - Fibromyalgia
- Acute pain
  - Nociceptive pain
  - Post-operative pain
- Mood disorders
  - Anxiety disorders
    - Generalized anxiety disorder
    - Social anxiety disorder
    - Panic disorder
    - Obsessive compulsive disorder
    - Post-traumatic stress syndrome
  - Depression
  - Addiction
    - Cocaine dependence and withdrawal
    - Opioid dependence and withdrawal
    - Alcohol dependence and withdrawal
    - Nicotine dependence and withdrawal
- Gastrointestinal disorders
  - Inflammatory bowel disease
  - Irritable bowel syndrome
- Genitourinary disorders
  - Urinary incontinence
  - Interstitial colitis
  - Sexual dysfunction

Many of the members of the genus of compounds of formula (1) exhibit high affinity for N-type channels. Thus, as described below, they are screened for their ability to interact with N-type channels as an initial indication of desirable function. It is desirable that the compounds exhibit IC_{50} values of <1 μM. The IC_{50} is the concentration which inhibits 50% of the calcium flux at a particular applied potential.

[0024] Many of the invention compounds also inhibit T-type channels. Thus, these compounds are useful in treating the following conditions:

- Cardiovascular disease
  - Hypertension
  - Arrhythmia
    - Atrial fibrillation
  - Congestive heart failure
  - Angina pectoris
- Epilepsy
  - Partial seizures
    - Temporal lobe epilepsy
  - Absence seizures
  - Generalized seizures
  - Tonic/clonic seizures
- Diabetes
- Cancer
- Chronic pain
  - Neuropathic pain
    - Diabetic peripheral neuropathy
    - Post-herpetic neuralgia
    - Trigeminal neuralgia
    - Cancer pain
    - AIDS related neuropathy
  - Inflammatory pain
    - Osteoarthritis pain
    - Rheumatoid arthritis pain
    - Fibromyalgia
- Acute pain
  - Nociceptive pain
  - Post-operative pain

[0025] There are two distinguishable types of calcium channel inhibition. The first, designated "open channel blockage," is conveniently demonstrated when displayed calcium channels are maintained at an artificially negative resting potential of about -100 mV (as distinguished from the typical endogenous resting maintained potential of about -70 mV). When the displayed channels are abruptly depolarized under these conditions, calcium ions are caused to flow through the channel and exhibit a peak current flow which then decays. Open channel blocking inhibitors diminish the current exhibited at the peak flow and can also accelerate the rate of current decay.

[0026] This type of inhibition is distinguished from a second type of block, referred to herein as "inactivation inhibition." When maintained at less negative resting potentials, such as the physiologically important potential of -70 mV, a certain percentage of the channels may undergo conformational change, rendering them incapable of being activated -- *i.e.*, opened -- by the abrupt depolarization. Thus, the peak current due to calcium ion flow will be diminished not because the open channel is blocked, but because some of the channels are unavailable for opening (inactivated). "Inactivation" type inhibitors increase the percentage of receptors that are in an inactivated state.

[0027] In order to be maximally useful in treatment, it is also helpful to assess the side reactions which might occur. Thus, in addition to being able to modulate a particular calcium channel, it is desirable that the compound has very low activity with respect to the HERG K^+ channel which is expressed in the heart. Compounds that block this channel with high potency may cause reactions which are fatal. Thus, for a compound that modulates the calcium channel, it should also be shown that the HERG K^+ channel is not inhibited. Similarly, it would be undesirable for the compound to inhibit cytochrome p450 since this enzyme is required for drug detoxification. Finally, the compound will be evaluated for calcium ion channel type specificity by comparing its activity among the various types of calcium channels, and specificity for one particular channel type is preferred. The compounds which progress through these tests successfully are then examined in animal models as actual drug candidates.

Synthesis of the Invention Compounds

[0028] The compounds of the invention modulate the activity of calcium channels; in general, said modulation is the inhibition of the ability of the channel to transport calcium. As described below, the effect of a particular compound on calcium channel activity can readily be ascertained in a routine assay whereby the conditions are arranged so that the channel is activated, and the effect of the compound on this activation (either positive or negative) is assessed. Typical assays are described hereinbelow.

[0029] The compounds of the invention may have ionizable groups so as to be capable of preparation as pharmaceutically acceptable salts. These salts may be acid addition salts involving inorganic or organic acids or the salts may, in the case of acidic forms of the compounds of the invention be prepared from inorganic or organic bases. Suitable pharmaceutically acceptable acids and bases are well-known in the art, such as hydrochloric,

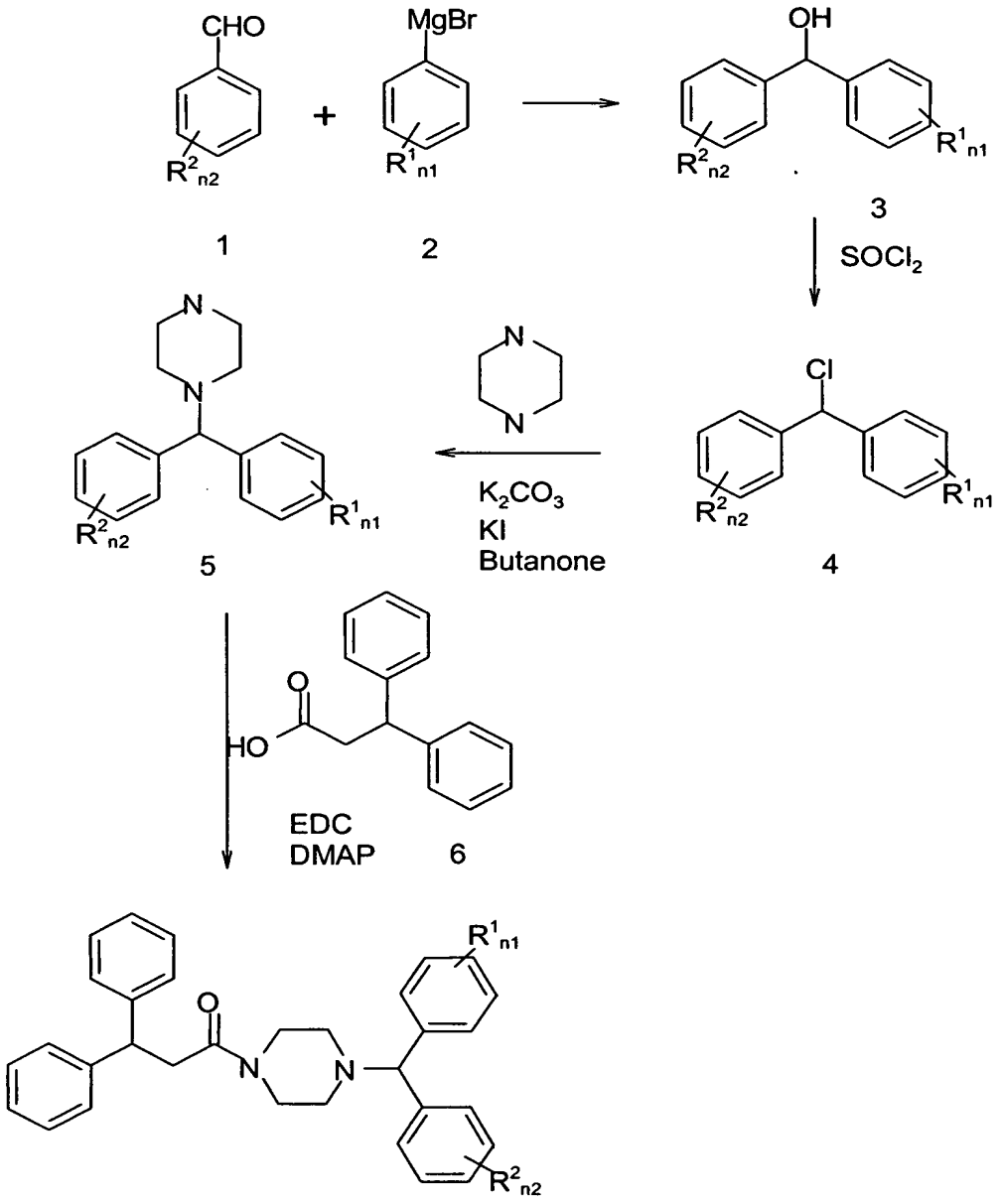
sulphuric, citric, acidic, or tartaric acids and potassium hydroxide, sodium hydroxide, ammonium hydroxide, caffeine, various amines, and the like. Methods for preparation of the appropriate salts are well-established in the art.

[0030] In addition, in some cases, the compounds of the invention contain one or more chiral centers; this is particularly the case where only a single ring A, B, C or D is substituted. The invention includes the isolated stereoisomeric forms as well as mixtures of stereoisomers in varying degrees of chiral purity.

[0031] The compounds of the invention may be synthesized using conventional methods. Illustrative of such methods are Schemes 1-3:

[0032] Reaction Scheme 1 was used to prepare compounds of the invention with substituents in ring A and/or B, where the substituent does not bridge these rings. This scheme may also be used to prepare compounds with substituents in rings C and D by modifying the benzhydril carboxylic acid in the last step of the synthesis. Thus, the method set forth in Reaction Scheme 1 was used to synthesize compounds 1-4, 6, 7, 9-15, 17-26, 29, 30, 35 and 36.

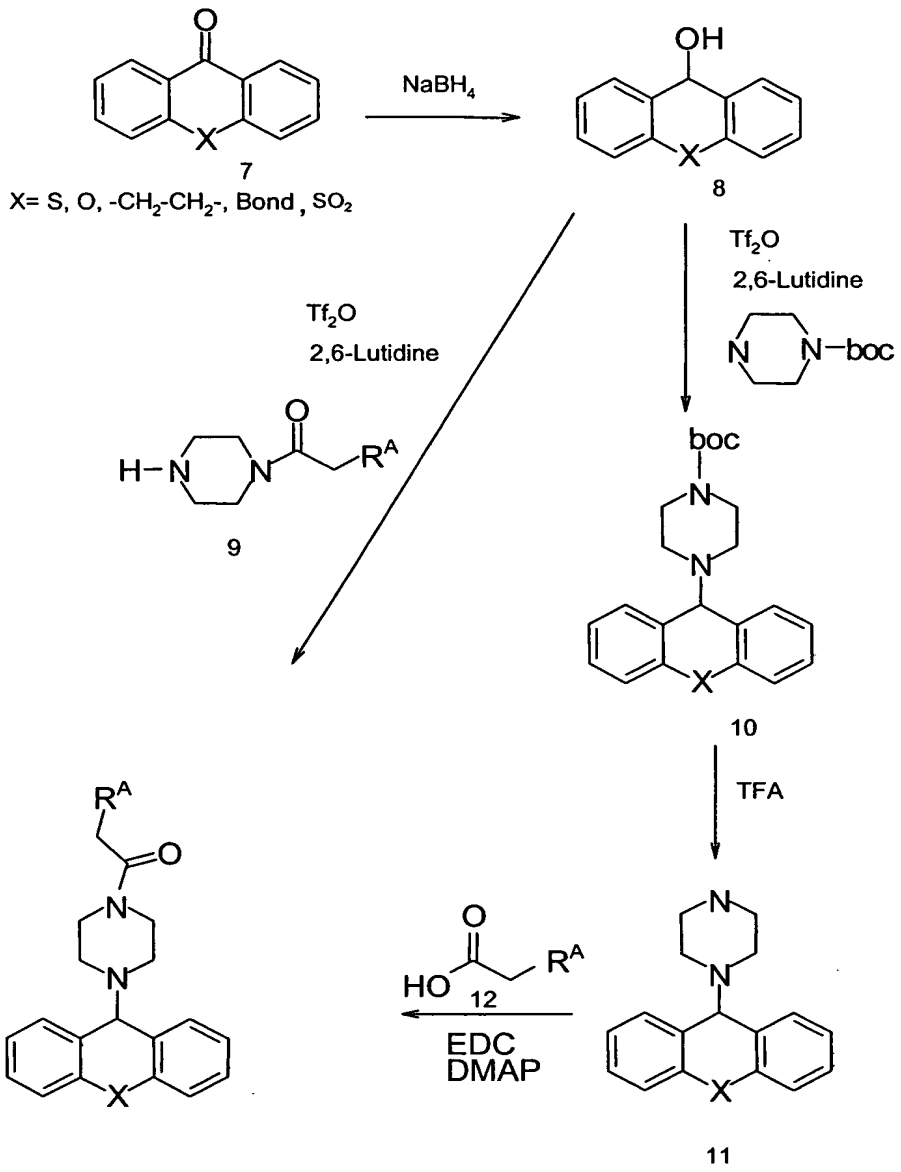
Reaction Scheme 1



[0033] Similarly, when substituents are present in ring C and/or D, a compound of formula 4 (but where R^2 and R^1 are replaced by R^4 and R^5) is converted to a compound of formula 6 by reaction with acetic acid containing a leaving group on the α carbon.

[0034] For those compounds where a bridge is formed between rings A and B, Reaction Scheme 2 is employed. Thus, this Reaction Scheme was used to synthesize compounds P16, P27, P28, P31 and P32.

Reaction Scheme 2

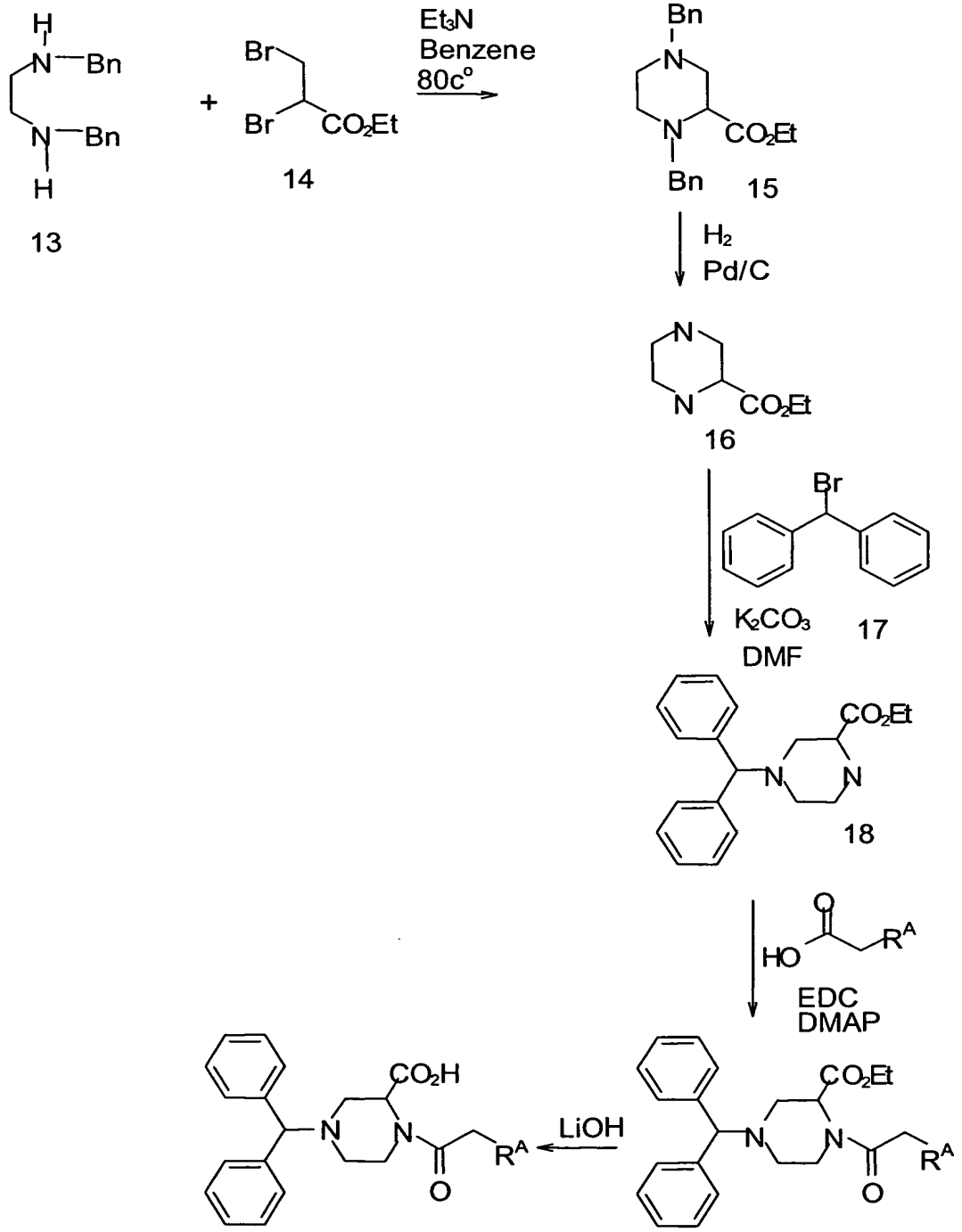


wherein R^A is benzhydril. In instances where rings C and D are bridged, R^A is a benzhydril derivative containing the "X" bridge.

[0035] In all of these cases, the bridged benzhydrils may be further substituted by R^1-R^2 or R^4-R^5 as set forth hereinabove.

[0036] For synthesis of compounds with substituents in the piperazine ring, Reaction Scheme 3 is employed. Thus, Reaction Scheme 3 was used to synthesize compounds P5 and P8.

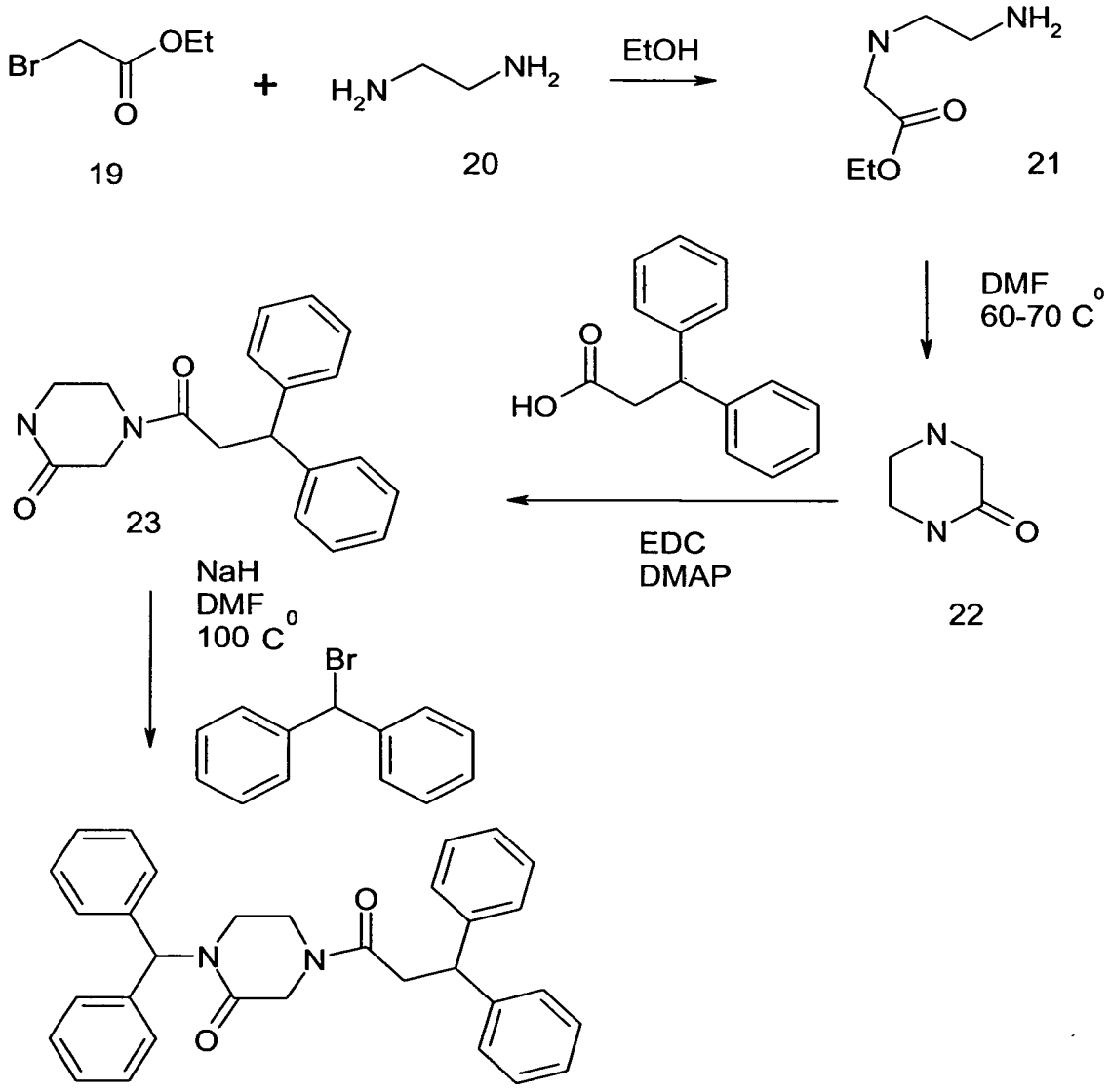
Reaction Scheme 3



wherein R^A, as defined above, is benzhydril.

[0037] For synthesis of compounds where the substituent on the piperazine ring is a keto group, Reaction Scheme 4 is employed.

Reaction Scheme 4



[0038] Using the methods described above, all of the compounds of Figure 1 are synthesized.

[0039] Compound P34 was synthesized using Reaction Scheme 4.

Preferred Embodiments

[0040] The compounds of formula (1) are defined as shown in terms of the embodiments of their various substituents. The substituents may include optionally substituted alkyl, aryl, alkaryl and the like.

[0041] As used herein, the terms "alkyl," "alkenyl" and "alkynyl" include straight-chain, branched-chain and cyclic monovalent substituents, containing only C and H when they are unsubstituted. Examples include methyl, ethyl, isobutyl, cyclohexyl, cyclopentylethyl, 2-propenyl, 3-butynyl, and the like. Typically, the alkyl, alkenyl and alkynyl substituents contain 1-10C (alkyl) or 2-10C (alkenyl or alkynyl). Preferably they contain 1-6C (lower alkyl) or 2-6C (lower alkenyl or lower alkynyl).

[0042] Heteroalkyl, heteroalkenyl and heteroalkynyl are similarly defined but may contain 1 or more O, S or N heteroatoms or combinations thereof within the backbone residue.

[0043] "Acyl" encompasses the definitions of alkyl, alkenyl, alkynyl, each of which is coupled to an additional residue through a carbonyl group, heteroacyl includes the related heteroforms.

[0044] "Aromatic" moiety or "aryl" moiety refers to a monocyclic or fused bicyclic moiety such as phenyl or naphthyl; "heteroaromatic" also refers to monocyclic or fused bicyclic ring systems containing one or more heteroatoms selected from O, S and N. The inclusion of a heteroatom permits inclusion of 5-membered rings as well as 6-membered rings. Thus, typical aromatic/heteroaromatic systems include pyridyl, pyrimidyl, indolyl, benzimidazolyl, benzotriazolyl, isoquinolyl, quinolyl, benzothiazolyl, benzofuranyl, thienyl, furyl, pyrrolyl, thiazolyl, oxazolyl, imidazolyl and the like. Because tautomers are theoretically possible, phthalimido is also considered aromatic. Any monocyclic or fused ring bicyclic system which has the characteristics of aromaticity in terms of electron distribution throughout the ring system is included in this definition. Typically, the ring systems contain 5-12 ring member atoms.

[0045] Similarly, "arylalkyl" and "heteroarylalkyl" refer to aromatic and heteroaromatic systems which are coupled to another residue through a carbon chain, including substituted or unsubstituted, saturated or unsaturated, carbon chains, typically of 1-8C, or the hetero forms thereof. These carbon chains may also include a carbonyl group, thus making them able to provide substituents as an acyl or heteroacyl moiety.

[0046] In general, any alkyl, alkenyl, alkynyl, acyl, or aryl group contained in a substituent may itself optionally be substituted by additional substituents. The nature of these substituents

is similar to those recited with regard to the primary substituents themselves. Thus, where an embodiment of a substituent is alkyl, this alkyl may optionally be substituted by the remaining substituents listed as substituents where this makes chemical sense, and where this does not undermine the size limit of alkyl *per se*; *e.g.*, alkyl substituted by alkyl or by alkenyl would simply extend the upper limit of carbon atoms for these embodiments. However, alkyl substituted by aryl, amino, alkoxy, and the like would be included. The features of the invention compounds are defined by formula (1) and the nature of the substituents is less important as long as the substituents do not interfere with the stated biological activity of this basic structure.

[0047] Non-interfering substituents on Ar^1 or Ar^2, include, but are not limited to, alkyl, alkenyl, alkynyl, halo, OR, NR_2, SR, -SOR, $-SO_2R$, -OCOR, -NRCOR, $-NRCONR_2$, -NRCOOR, $-OCONR_2$, -RCO, -COOR, SO_2R, NRSOR, $NRSO_2R$, $-SO_3R$, $-CONR_2$, SO_2NR_2, wherein each R is independently H or alkyl (1-8C), -CN, $-CF_3$, and NO_2, and like substituents. R^3 and R^4 can also be H. Preferred embodiments for R^3 and R^4 are H, alkyl (1-10C) or a heteroatom-containing form thereof, each optionally substituted, especially (1-4C) alkyl; alkoxy (1-8C), acylamido, aryloxy, arylalkyloxy, especially wherein the aryl group is a phthalimido group, and alkyl or arylalkyl amine.

[0048] Particularly preferred embodiments of the invention are those wherein only one or two of the rings are substituted and wherein the number of substituents on a single ring is three or less. Particularly preferred substituents for rings A and/or B include halo, especially chloro; CF_3; optionally substituted, optionally heteroatom-containing alkyl, alkenyl, aryl, alkyl aryl, alkenyl aryl, phenoxy, and the like. Where the substituents on these moieties contain alkyl or aryl groups, these also may optionally be substituted. Also preferred are bridging substituents containing heteroatoms. The bridge between rings A and B or C and D preferably contain 1-3 members including preferably $(CR_2)_m$ where m is 1-3; $(CR_2)_l$ NR $(CR_2)_l$ $(CR_2)_l$ $O(CR_2)_l$ $(CR_2)_l$ $S(CR_2)_l$ where S is optionally oxidized, CR_2, O, NR, and optionally oxidized S.

[0049] Particularly preferred substituents for the piperazine ring include COOR, especially COOH and COOEt, alkyl, and alkenyl, (as defined above and optionally containing heteroatoms and all optionally substituted) and halo.

[0050] Preferred substituents for rings C and D are similar to those for A and B.

Libraries and Screening

[0051] The compounds of the invention can be synthesized individually using methods known in the art *per se*, or as members of a combinatorial library.

[0052] Synthesis of combinatorial libraries is now commonplace in the art. Suitable descriptions of such syntheses are found, for example, in Wentworth, Jr., P., *et al., Current Opinion in Biol.* (1993) 9:109-115; Salemme, F.R., *et al., Structure* (1997) 5:319-324. The libraries contain compounds with various substituents and various degrees of unsaturation, as well as different chain lengths. The libraries, which contain, as few as 10, but typically several hundred members to several thousand members, may then be screened for compounds which are particularly effective against a specific subtype of calcium channel, *i.e.*, the N-type channel. In addition, using standard screening protocols, the libraries may be screened for compounds which block additional channels or receptors such as sodium channels, potassium channels and the like.

[0053] Methods of performing these screening functions are well known in the art. These methods can also be used for individually ascertaining the ability of a compound to agonize or antagonize the channel. Typically, the channel to be targeted is expressed at the surface of a recombinant host cell such as human embryonic kidney cells. The ability of the members of the library to bind the channel to be tested is measured, for example, by the ability of the compound in the library to displace a labeled binding ligand such as the ligand normally associated with the channel or an antibody to the channel. More typically, ability to antagonize the channel is measured in the presence of calcium ion and the ability of the compound to interfere with the signal generated is measured using standard techniques. In more detail, one method involves the binding of radiolabeled agents that interact with the calcium channel and subsequent analysis of equilibrium binding measurements including, but not limited to, on rates, off rates, K_d values and competitive binding by other molecules.

[0054] Another method involves the screening for the effects of compounds by electrophysiological assay whereby individual cells are impaled with a microelectrode and currents through the calcium channel are recorded before and after application of the compound of interest.

[0055] Another method, high-throughput spectrophotometric assay, utilizes loading of the cell lines with a fluorescent dye sensitive to intracellular calcium concentration and subsequent examination of the effects of compounds on the ability of depolarization by potassium chloride or other means to alter intracellular calcium levels.

[0056] As described above, a more definitive assay can be used to distinguish inhibitors of calcium flow which operate as open channel blockers, as opposed to those that operate by promoting inactivation of the channel. The methods to distinguish these types of inhibition are more particularly described in the examples below. In general, open-channel blockers are assessed by measuring the level of peak current when depolarization is imposed on a background resting potential of about -100 mV in the presence and absence of the candidate compound. Successful open-channel blockers will reduce the peak current observed and may accelerate the decay of this current. Compounds that are inactivated channel blockers are generally determined by their ability to shift the voltage dependence of inactivation towards more negative potentials. This is also reflected in their ability to reduce peak currents at more depolarized holding potentials (*e.g.*, -70 mV) and at higher frequencies of stimulation, *e.g.*, 0.2 Hz vs. 0.03 Hz.

Utility and Administration

[0057] For use as treatment of human and animal subjects, the compounds of the invention can be formulated as pharmaceutical or veterinary compositions. Depending on the subject to be treated, the mode of administration, and the type of treatment desired -- *e.g.*, prevention, prophylaxis, therapy; the compounds are formulated in ways consonant with these parameters. A summary of such techniques is found in Remington's Pharmaceutical Sciences, latest edition, Mack Publishing Co., Easton, PA, incorporated herein by reference.

[0058] In general, for use in treatment, the compounds of formula (1) may be used alone, as mixtures of two or more compounds of formula (1) or in combination with other pharmaceuticals. Depending on the mode of administration, the compounds will be formulated into suitable compositions to permit facile delivery.

[0059] Formulations may be prepared in a manner suitable for systemic administration or topical or local administration. Systemic formulations include those designed for injection (*e.g.*, intramuscular, intravenous or subcutaneous injection) or may be prepared for transdermal, transmucosal, or oral administration. The formulation will generally include a diluent as well as, in some cases, adjuvants, buffers, preservatives and the like. The compounds can be administered also in liposomal compositions or as microemulsions.

[0060] For injection, formulations can be prepared in conventional forms as liquid solutions or suspensions or as solid forms suitable for solution or suspension in liquid prior to injection or

as emulsions. Suitable excipients include, for example, water, saline, dextrose, glycerol and the like. Such compositions may also contain amounts of nontoxic auxiliary substances such as wetting or emulsifying agents, pH buffering agents and the like, such as, for example, sodium acetate, sorbitan monolaurate, and so forth.

[0061] Various sustained release systems for drugs have also been devised. See, for example, U.S. Patent No. 5,624,677.

[0062] Systemic administration may also include relatively noninvasive methods such as the use of suppositories, transdermal patches, transmucosal delivery and intranasal administration. Oral administration is also suitable for compounds of the invention. Suitable forms include syrups, capsules, tablets, as in understood in the art.

[0063] For administration to animal or human subjects, the dosage of the compounds of the invention is typically 0.1-15 mg/kg, preferably 0.1-1 mg/kg. However, dosage levels are highly dependent on the nature of the condition, the condition of the patient, the judgment of the practitioner, and the frequency and mode of administration.

[0064] The following examples are intended to illustrate but not to limit the invention.

Preparation 1

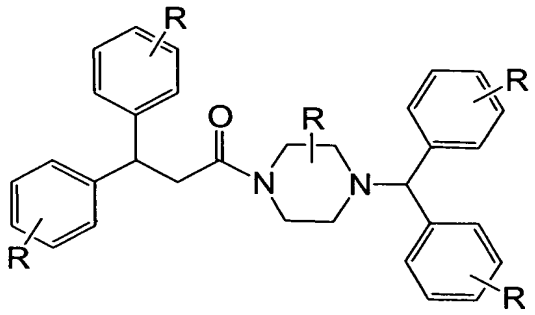
General Procedure for Preparation of Compounds of Formula (1) from Benzhydrilpiperazine Derivatives

[0065] N-(Diphenylmethyl)piperazine (0.5 mmole) is dissolved in dry THF (10 ml). To each reaction flask is added powdered K_2CO_3 and acid chloride of the formula Φ_2CHCH_2-CO-Cl (0.7 mmole), wherein one phenyl group is substituted. The reaction is stirred at RT for 2h and quenched with 105 NaOH (10 ml) and extracted with EtOAc (10 ml). The organic layer is washed with 10% NaOH (4x) and dried over sodium sulfate, concentrated, and purified by column chromatography (silica gel, 1:1 hex:EtOAc) to give the desired amide.

Preparation 2

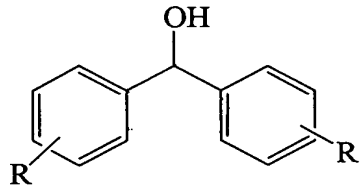
Model for Synthesis of Substituted

1-(4-Benzhydryl-piperazin-1-yl)-3,3-diphenyl-propan-1-one



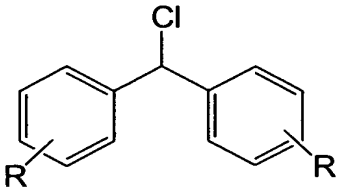
[0066] The model is conducted synthesizing the unsubstituted form.

A. Synthesis of Diphenyl-methanol



[0067] A solution of benzaldehyde (7.34 mmol) in dry ether (10 ml) was added slowly to a solution of phenylmagnesium bromide (2.3 ml, 6.98 mmol, 3.0 M in ether) under nitrogen. The mixture was heated to reflux for 1 hour then cooled to 0°C and hydrolysed with 1 N HCl (40 ml). The aqueous phase was extracted with ether (3X) and combined organic layer dried over $MgSO_4$. The crude product was purified using hexane: ethyl acetate (5:1) as eluant to give 1.5 g of pure product.

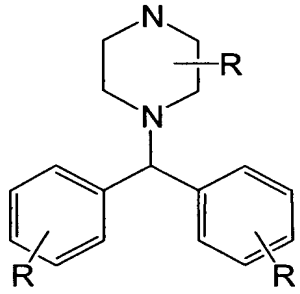
B. Synthesis of Cholorodiphenylmethane



[0068] To a solution of diphenyl carbinol (11.06 mmol) in dry benzene (20 ml) was added $SOCl_2$ (8.25 ml, 110 mmol) and anhydrous $CaCl_2$ (2g). The mixture was heated under reflux for 2 hours and then cooled and stirred at room temperature overnight. It was then filtered and

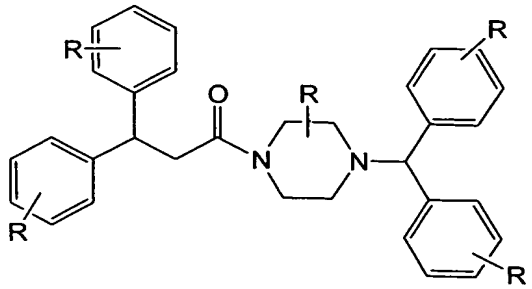
solvent removed *in vacuo* to give a pale yellow oil and was used in the next step without further purification.

C. Synthesis of 1-Benzhydryl-piperazine



[0069] A mixture of cholorodiphenylmethane (17.4 mmol) in butanone (20 ml), anhydrous piperazine (5.98g, 69.6 mmol), anhydrous K_2CO_3 (2.40g, 17.4 mmol) and KI (2.88 g, 17.4 mmol) was refluxed under nitrogen for 18 hours. The mixture was then cooled and filtered and the solvent removed *in vacuo*. The residue was dissolved in CH_2Cl_2 (100 ml) and washed with water (30 ml). Drying and removal of the solvent followed by chromatography (CH_2Cl_2: CH_3OH: NH_4OH 90:10:0.5) afforded desired product in 57% yield.

D. Synthesis of 1-(4-Benzhydryl-piperazin-1-yl)-3,3-diphenyl-propan-1-one



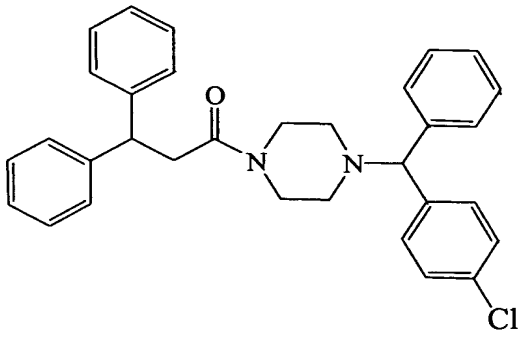
[0070] To a solution of 1-Benzhydryl-piperazine (2.08 mmol) in dry CH_2Cl_2 (40 ml) was added 3,3-diphenylpropanoic acid (0.472 g, 2.08 mmol) under nitrogen. To the reaction was added EDC (0.797 g, 4.16 mmol) and DMAP (cat) and the reaction mixture stirred under nitrogen at room temperature overnight. The reaction was then concentrated under reduced pressure. The residue dissolved in ethyl acetate: water (10:1) (150 ml). The organic was washed with water (30 ml, 2x) and 10% NaOH (30 ml) and dried over $MgSO_4$ and evaporated to dryness. The resulting residue was purified by column chromatography using hexane: ethyl acetate (3:1) to give title compound in 78% yield.

[0071] In the foregoing procedure, substituted forms of the reagents - as noted by "R" - are employed.

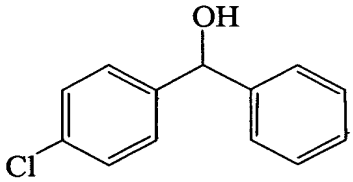
Example 1

Synthesis of

1-{4-[(4-Chloro-phenyl)-phenyl-methyl]-piperazin-1-yl}-3,3-diphenyl-propan-1-one

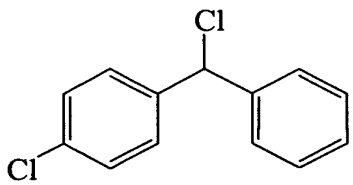


A. Synthesis of (4-Chloro-phenyl)-phenyl-methanol



[0072] A solution of 4-chlorobenzaldehyde (1.03 g, 7.34 mmol) in dry ether (10 ml) was added slowly to a solution of phenylmagnesium bromide (2.3 ml, 6.98 mmol, 3.0 M in ether) under nitrogen. The mixture was heated to reflux for 1 hour then cooled to 0°C and hydrolysed with 1 N HCl (40 ml). The aqueous phase was extracted with ether (3X) and combined organic layer dried over $MgSO_4$. The crude product was purified using hexane: ethyl acetate (5:1) as eluant to give 1.5g of pure product.

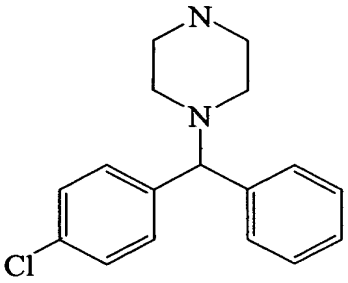
B. Synthesis of 1-Chloro-4-(chloro-phenyl-methyl)-benzene



[0073] To a solution of (4-chloro-phenyl)-phenyl-methanol (2.41g, 11.06 mmol) in dry benzene (20 ml) was added $SOCl_2$ (8.25 ml, 110 mmol) and anhydrous $CaCl_2$ (2 g). The

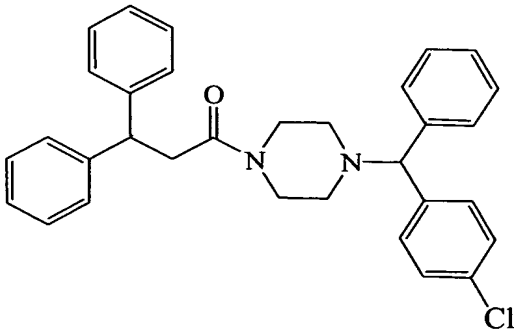
mixture was heated under reflux for 2 hours and then cooled and stirred at r.t. overnight. It was then filtered and solvent removed *in vacuo* to give a pale yellow oil and was used in the next step without further purification.

C. Synthesis of 1-[(4-Chloro-phenyl)-phenyl-methyl]-piperazine



[0074] A mixture of 1-chloro-4-(chloro-phenyl-methyl)-benzene (4.12 g, 17.4 mmol) in butanone (20 ml), anhydrous piperazine (5.98 g, 69.6 mmol), anhydrous K_2CO_3 (2.40 g, 17.4 mmol) and KI (2.88 g, 17.4 mmol) was refluxed under nitrogen for 18 hours. The mixture was then cooled and filtered and the solvent removed *in vacuo*. The residue was dissolved in CH_2Cl_2 (100 ml) and washed with water (30 ml). Drying and removal of the solvent followed by chromatography (CH_2Cl_2: CH_3OH: NH_4OH 90:10:0.5) afforded desired product in 57% yield.

D. Synthesis of 1-{4-[(4-Chloro-phenyl)-phenyl-methyl]-piperazin-1-yl}-3,3-diphenyl-propan-1-one

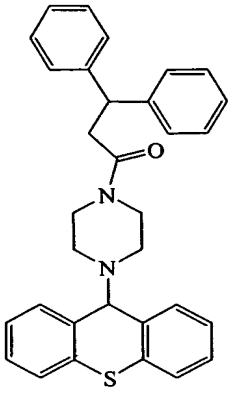


[0075] To a solution of 1-[(4-chloro-phenyl)-phenyl-methyl]-piperazine (0.59 g, 2.08 mmol) in dry CH_2Cl_2 (40 ml) was added 3,3-diphenylpropanoic acid (0.472 g, 2.08 mmol) under nitrogen. To the reaction was added EDC (0.797 g, 4.16 mmol) and DMAP (cat) and the reaction mixture stirred under nitrogen at room temp. over night. The reaction was then concentrated under reduced pressure. The residue dissolved in ethyl acetate: water (10:1)

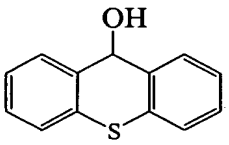
(150 ml). The organic was washed with water (30 ml, 2x) and 10% NaOH (30 ml) and dried over $MgSO_4$ and evaporated to dryness. The resulting residue was purified by column chromatography using hexane: ethyl acetate (3:1) to give desired product in 78% yield.

Example 2

Synthesis of 3,3-Diphenyl-1-{4-(9H-thioxanthen-9-yl)-piperazin-1-yl}-propan-1-one



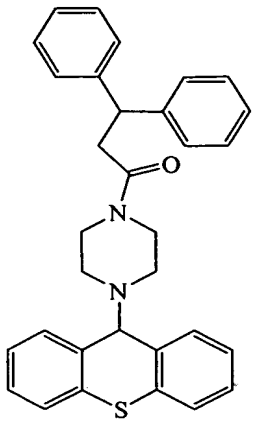
A. Synthesis of 9H-Thioxanthen-9-ol



[0076] Xanthone (2.1 g, 9.9 mmols) was reduced with an excess of sodium borohydride (5.0 g, 0.13 mol) in 95% EtOH (50 mL). After stirring for 45 min., 10 mL of water was added and the mixture warmed on a steam bath. Addition of ice caused the precipitation of thioxanthen-9-ol, which was then washed with water and dried. Yield 2.0 g, mp. 102-105°C.

B. Synthesis of

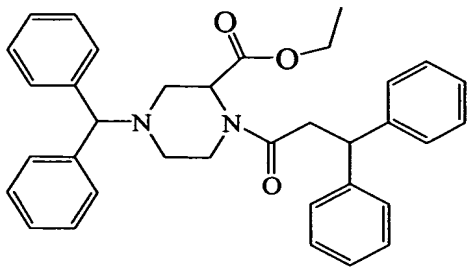
3,3-Diphenyl-1-{4-(9H-thioxanthen-9-yl)-piperazin-1-yl}-propan-1-one



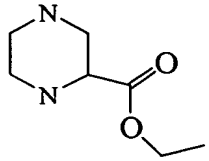
[0077] The thioxanthen-9-ol (1.0 g, 4.66 mmol) was dissolved in dry CH_2Cl_2 (25 mL) and 3.0 mL of 2-6-Lutidine and cooled in an ice-H_2O bath. Triflic anhydride (0.87 mL, 5.12 mmol) was added via syringe, and the resulting red reaction mixture was stirred at 0°C. After 30 min, compound 9 (3,3-diphenyl-1-piperazin-1-yl-propan-1-one) (1.64 g, 5.6 mmol) was added at 0°C and stirred at this temperature for 1 hour. The reaction mixture was then stirred at room temperature overnight. The mixture was quenched with water, and the organic phase washed with water, saturated NaCl, dried over $MgSO_4$, and evaporated. The crude product was purified by column chromatography on silica (Hexane:EtOAc 1:1) to give 0.75 g pure product.

Example 3

Synthesis of 4-Benzhydryl-1-(3,3-diphenyl-propionyl)-piperazine-2-carboxylic acid ethyl ester

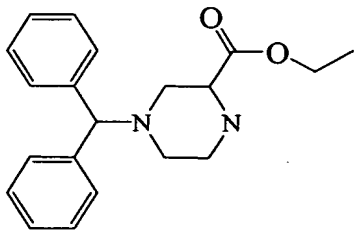


A. Synthesis of Piperazine 2- carboxylic acid ethyl ester



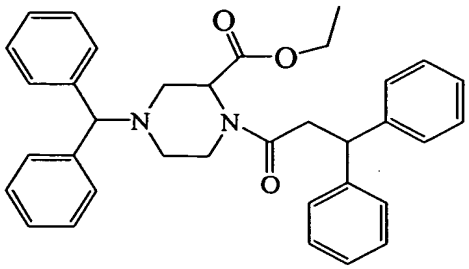
[0078] Compound 15 (1 eq.) was dissolved, with warming, in EtOH, and hydrogenated over 10% Pd-C at room temperature and atmospheric pressure until H_2 uptake ceased. The mixture was filtered through Celite and the solvent evaporated, giving an oil which was distilled under reduced pressure.

B. Synthesis of 4-Benzhydryl-piperazine-2-carboxylic acid ethyl ester



[0079] A mixture of piperazine 2- carboxylic acid ethyl ester 16 (1.0 g, 6.32 mmol), bromodiphenylmethane 17 (1.56 g, 6.32 mmol), K_2CO_3 (1.05 g, 7.58 mmol) in anhydrous DMF (20 ml) was stirred at room temperature for three days. The mixture was then diluted with EtOAc (100 ml), washed with water (2X 30 ml), brine (2X 30 ml), dried over $MgSO_4$ and evaporated. Purification by column chromatography using CH_2Cl_2 : CH_3OH (15:1) gave product in 75% yield.

C. Synthesis of 4-Benzhydryl-1-(3,3-diphenyl-propionyl)-piperazine-2-carboxylic acid ethyl ester

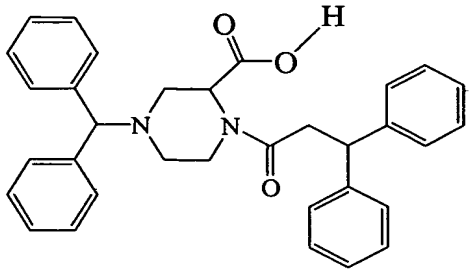


[0080] To a solution of 4-benzhydryl-piperazine-2-carboxylic acid ethyl ester (0.5 g, 1.54 mmol) in dry CH_2Cl_2 (25 ml) was added 3,3-diphenylpropanoic acid (0.35 g, 1.54 mmol) under nitrogen. To the reaction was added EDC (0.59 g, 3.08 mmol) and DMAP (cat) and the

reaction mixture stirred under nitrogen at room temperature overnight. The reaction was then concentrated under reduced pressure. The residue dissolved in ethyl acetate: water (10:1) (100 ml). The organic was washed with water (20 ml, 2x) and 10% NaOH (20 ml) and dried over $MgSO_4$ and evaporated to dryness. The resulting residue was purified by column chromatography using hexane: ethyl acetate (3:1) to give title compound in 73% yield.

Example 4

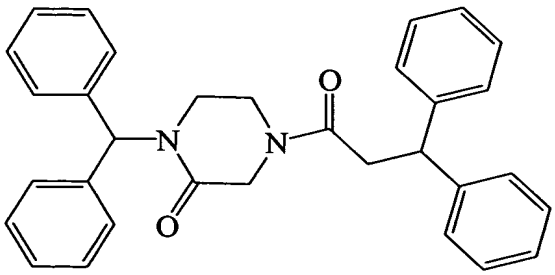
Synthesis of 4-Benzhydryl-1-(3,3-diphenyl-propionyl)-piperazine-2-carboxylic acid



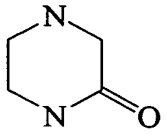
[0081] A mixture of 4-benzhydryl-1-(3,3-diphenyl-propionyl)-piperazine-2-carboxylic acid ethyl ester (0.51 g, 0.957 mmol), and $LiOH \cdot H_2O$ (0.12 g, 2.87 mmol) in THF/MeOH/H_2O (15:5:5) was stirred at room temperature for two days. The solvent was evaporated under reduced pressure, the residue was dissolved in water, acidified with 1N HCl to pH 3. The product was extracted with EtOAc, dried with $MgSO_4$, and evaporated under reduced pressure. The product was purified by column chromatography (CH_2Cl_2:MeOH 15:1) to give the title compound in 95% yield.

Example 5

Synthesis of 1-Benzhydryl-4-(3,3-diphenyl-propionyl)-piperazin-2-one

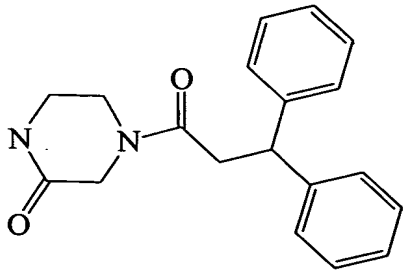


A. Synthesis of 2-ketopiperazine



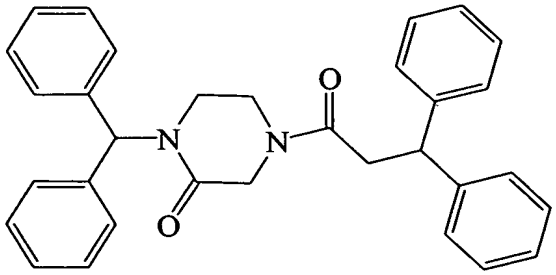
[0082] A solution of bromoethylacetate (10 g, 59.8 mmol) in absolute ethanol (80 ml) is slowly added at room temperature to a solution of ethylenediamine (36 g, 598 mmol) in absolute ethanol (140 ml). The addition requires about three hours and the mixture is allowed to stand for an additional two hours. Sodium ethoxide (21% wt, 22 ml, 59.8 mmol) was added dropwise. The mixture was stirred at room temperature overnight and solvent was then evaporated. DMF (40 ml) was added to residue and stirred at 60-70°C for 24 hours. The salt was filtered and the solvent was evaporated. The residue was purified by column chromatography using CH_2Cl_2: MeOH: NH_4OH (90: 10: 0.1) to give a yellow solid in 45% yield.

B. Synthesis of 4-(3,3-diphenyl-propionyl)-piperazin-2-one



[0083] To a solution of 2-ketopiperazine (0.7 g, 7.0 mmol) in dry CH_2Cl_2 (30 ml) was added 3,3-diphenylpropanoic acid (1.9 g, 8.4 mmol) under nitrogen. To the reaction was added EDC (1.7 g, 9.1 mmol) and DMAP (cat) and the reaction mixture stirred under nitrogen at room temperature overnight. The reaction was then concentrated under reduced pressure. The residue dissolved in ethyl acetate: water (10:1) (100 ml). The organic was washed with water (20 ml, 2x) and 10% NaOH (20 ml) and dried over $MgSO_4$ and evaporated to dryness. The resulting residue was purified by column chromatography using hexane: ethyl acetate (2:1) to give product in 70% yield.

C. Synthesis of 1-Benzhydryl-4-(3,3-diphenyl-propionyl)-piperazin-2-one



[0084] To a solution of 4-(3,3-diphenyl-propionyl)-piperazin-2-one (0.5 g, 1.62 mmol) in dry DMF (15 ml) was added NaH (60%, 75 mg, 1.86 mmol) and resulting mixture stirred for half an hour. To this mixture bromodiphenylmethane (0.40 g, 1.62 mmol) was added and the mixture stirred at 100°C over night. It was then cooled, EtOAc (100 ml) was added and washed with water (2X), brine (1X). The organic phase was then dried and evaporated to give a residue which upon column chromatography using CH_2Cl_2: MeOH (20: 1) gave the title compound in 65% yield.

Example 6

Assessment of Calcium Channel Blocking Activity

[0085] Antagonist activity was measured using whole cell patch recordings on human embryonic kidney cells either stably or transiently expressing rat $\alpha_{1B}+\alpha_{2b}+\beta_{1b}$ channels (N-type channels) with 5 mM barium as a charge carrier.

[0086] For transient expression, host cells, such as human embryonic kidney cells, HEK 293 (ATCC# CRL 1573) were grown in standard DMEM medium supplemented with 2 mM glutamine and 10% fetal bovine serum. HEK 293 cells were transfected by a standard calcium-phosphate-DNA coprecipitation method using the rat $\alpha_{1B} + \beta_{1b} + \alpha_2\delta$ N-type calcium channel subunits in a vertebrate expression vector (for example, see *Current Protocols in Molecular Biology*).

[0087] After an incubation period of from 24 to 72 hrs the culture medium was removed and replaced with external recording solution (see below). Whole cell patch clamp experiments were performed using an Axopatch 200B amplifier (Axon Instruments, Burlingame, CA) linked to an IBM compatible personal computer equipped with pCLAMP software. Borosilicate glass patch pipettes (Sutter Instrument Co., Novato, CA) were polished (Microforge, Narishige, Japan) to a resistance of about 4 MΩ when filled with cesium methanesulfonate internal solution (composition in MM: 109 $CsCH_3SO_4$, 4 $MgCl_2$, 9 EGTA, 9 HEPES, pH 7.2). Cells were bathed

in 5 mM Ba^{++} (in mM: 5 $BaCl_2$, 1 $MgCl_2$, 10 HEPES, 40 tetraethylammonium chloride, 10 glucose, 87.5 CsCl pH 7.2). Current data shown were elicited by a train of 100 ms test pulses at 0.066 Hz from -100 mV and/or -80 mV to various potentials (min. -20 mV, max. +30 mV). Drugs were perfused directly into the vicinity of the cells using a microperfusion system.

[0088] Normalized dose-response curves were fit (Sigmaplot 4.0, SPSS Inc., Chicago, IL) by the Hill equation to determine IC_{50} values. Steady-state inactivation curves were plotted as the normalized test pulse amplitude following 5 s inactivating prepulses at +10 mV increments. Inactivation curves were fit (Sigmaplot 4.0) with the Boltzman equation, I_{peak} (normalized)=1/(1+exp((V-V_h)z/25.6)), where V and V_h are the conditioning and half inactivation potentials, respectively, and z is the slope factor.

[0089] Using the procedure set forth above, various compounds of the invention were tested for their ability to block N-type calcium channels. The results show IC_{50} values in the range of 0.05≥1 μM, as shown in Table 1.

Table 1: Block of α1B N-type Channels

Compound	0.067 Hz IC_{50} (μM)	0.2 Hz IC_{50} (μM)
P1	0.100	0.074
P2	0.200	0.105
P3	0.291	0.111
P4	0.213	0.114
P5	0.160	0.120
P6	0.170	0.120
P7	0.213	0.137
P8	0.230	0.140
P9	0.230	0.170
P10 (HCl)	0.300	0.190
P10	0.550	0.450
P11	0.370	0.190
P12	0.340	0.190
P13	0.300	0.210
P14	0.320	0.210
P15	0.348	0.217
P16	0.290	0.220
P17	0.286	0.233
P18	0.324	0.237
P19	0.360	0.249
P20	0.320	0.250
P21	0.437	0.252
P22	0.538	0.301

Compound	0.067 Hz IC_{50} (μM)	0.2 Hz IC_{50} (μM)
P23	0.490	0.310
P24	0.600	0.380
P25	1.090	0.513
P26	0.710	0.533
P27	0.854	0.552
P29 (HCl)	>1	>1
P29	>1	>1
P30	>1	>1
P32 (HCl)	>1	0.830
P34	0.737	0.680
P35	0.211	0.092
P36	0.114	0.044
P37	0.162	0.024
P38	0.200	0.160
P39	0.240	0.190
P41	0.420	0.390
P42	1.900	1.490
P43	0.167	0.083
P44	0.360	0.310
P45	0.230	0.220
P46	0.647	0.452
P47	0.237	0.138
P48	0.121	0.052
P49	0.340	0.320
P50	0.180	0.140

[0090] As shown in Table 1, the nature of the substituent has an influence on the IC_{50} value.

Example 7

Additional Methods

[0091] The methods of Example 6 were followed with slight modifications as will be apparent from the description below.

A. Transformation of HEK cells:

[0092] N-type calcium channel blocking activity was assayed in human embryonic kidney cells, HEK 293, stably transfected with the rat brain N-type calcium channel subunits (α_{1B} + $\alpha_{2\delta}$ +β_{1b} cDNA subunits). Alternatively, N-type calcium channels (α_{1B} + $\alpha_{2\delta}$ +β_{1b} cDNA subunits), L-type channels (α_{1C} + $\alpha_{2\delta}$ + β_{1b} cDNA subunits) and P/Q-type channels (α_{1A} + $\alpha_{2\delta}$ +β_{1b} cDNA subunits) were transiently expressed in HEK 293 cells. Briefly, cells were cultured in

Dulbecco's modified eagle medium (DMEM) supplemented with 10% fetal bovine serum, 200 U/ml penicillin and 0.2 mg/ml streptomycin at 37°C with 5% CO_2. At 85% confluency cells were split with 0.25% trypsin/1 mM EDTA and plated at 10% confluency on glass coverslips. At 12 hours the medium was replaced and the cells transiently transfected using a standard calcium phosphate protocol and the appropriate calcium channel cDNAs. Fresh DMEM was supplied and the cells transferred to 28°C/5% CO_2. Cells were incubated for 1 to 2 days to whole cell recording.

B. Measurement of Inhibition:

[0093] Whole cell patch clamp experiments were performed using an Axopatch 200B amplifier (Axon Instruments, Burlingame, CA) linked to a personal computer equipped with pCLAMP software. The external and internal recording solutions contained, respectively, 5 mM $BaCl_2$, 1 mM $MgCl_2$, 10 mM HEPES, 40 mM TEACl, 10 mM glucose, 87.5 mM CsCl (pH 7.2) and 108 mM CsMS, 4 mM $MgCl_2$, 9 mM EGTA, 9 mM HEPES (pH 7.2). Currents were typically elicited from a holding potential of -80 mV to +10 mV using Clampex software (Axon Instruments). Typically, currents were first elicited with low frequency stimulation (0.03 Hz) and allowed to stabilize prior to application of the compounds. The compounds were then applied during the low frequency pulse trains for two to three minutes to assess tonic block, and subsequently the pulse frequency was increased to 0.2 Hz to assess frequency dependent block. Data were analyzed using Clampfit (Axon Instruments) and SigmaPlot 4.0 (Jandel Scientific).

[0094] Table 2 shows the results obtained with several compounds of the invention which are selective for N-type channels.

Table 2: Selectivity of Compounds for N-type Ca^{2+} Channels

Tested at 0.1 Hz, 5 mM Ba^{2+}

Compound	N-type IC_{50} (μM)	P/Q-type IC_{50} (μM)	L-type IC_{50} (μM)	P/Q:N ratio	L:N ratio
P1	0.19	0.97	19.6	5.1:1	103:1
P2	0.113	1.632	6.6	14:1	58:1
P3	0.185	7.59	>>10	41:1	>>54:1
P4	0.251	>>10	>>10	>>40:1	>>40:1
P5	0.073	5.0	210	69:1	2877:1
P6	0.16	4.5	133	28:1	831:1
P7	0.101	6.5	15.8	64:1	156:1
P8	0.36	3.4	37.1	9.4:1	103:1`
P18	0.217	3.59	13.37	17:1	62:1

P29	0.385	26	126	68:1	327:1
P35	0.209	7.03	106	34:1	507:1
P36	0.206	0.93	8.5	5:1	41:1
P47	0.197	1.86	4.37	9:1	22:1

[0095] The results shown in Table 2 are shown graphically in Figures 2-5. As was the case for IC_{50} values, specificity for a particular type of channel is dependent on the nature of the substituents.

Example 8

Block of α_{1G} T-type Channels

[0096] Standard patch-clamp techniques were employed to identify blockers of T-type currents. Briefly, previously described HEK cell lines stably expressing human α_{1G} subunits were used for all the recordings (passage #: 4-20, 37° C, 5% CO_2). To obtain T-type currents, plastic dishes containing semi-confluent cells were positioned on the stage of a ZEISS AXIOVERT S100 microscope after replacing the culture medium with external solution (see below). Whole-cell patches were obtained using pipettes (borosilicate glass with filament, O.D.: 1.5 mm, I.D.: 0.86 mm, 10 cm length), fabricated on a SUTTER P-97 puller with resistance values of ~5 MΩ (see below for internal medium).

Table 3: External Solution 500 ml – pH 7.4, 265.5 mOsm

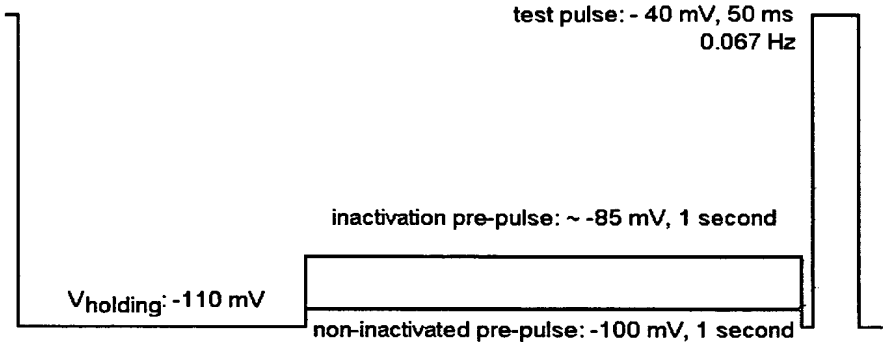
Salt	*Final mM*	*Stock M*	*Final ml*
CsCl	132	1	66
$CaCl_2$	2	1	1
$MgCl_2$	1	1	0.5
HEPES	10	0.5	10
glucose	10	----------	0.9 grams

Table 4: Internal Solution 50 ml – pH 7.3 with CsOH, 270 mOsm

Salt	*Final mM*	*Stock M*	*Final ml*
Cs-Methanesulfonate	108	----------	1.231 gr/50 ml
$MgCl_2$	2	1	0.1
HEPES	10	0.5	1
EGTA-Cs	11	0.25	2.2
ATP	2	0.2	0.025 (1 aliquot / 2.5 ml)

T-type currents were reliably obtained by using two voltage protocols:
(1) "non-inactivating", and
(2) "inactivation"

[0097] In the non-inactivating protocol, the holding potential is set at –110 mV and with a pre-pulse at –100 mV for 1 second prior to the test pulse at –40 mV for 50 ms; in the inactivation protocol, the pre-pulse is at approximately –85 mV for 1 second, which inactivates about 15% of the T-type channels, as shown below.



[0098] Test compounds were dissolved in external solution, 0.1-0.01 % DMSO. After ~10 min rest, they were applied by gravity close to the cell using a WPI microfil tubing. The "non-inactivated" pre-pulse was used to examine the resting block of a compound. The "inactivated" protocol was employed to study voltage-dependent block, but the initial data shown below were mainly obtained using the non-inactivated protocol only. IC_{50} values are shown for various compounds of the invention in Table 5.

Table 5: Block of α_{1G} T-type Channels

Compound	100 mV IC_{50} (μM)	80 mV IC_{50} (μM)
P6	0.081	-
P9	>1	-
P13	<1	-
P15	0.063	-
P17	No effect	-
P18	0.035	-
P19	0.745	-
P29	0.033	0.004
P30	>1	-
P31	0.371	-
P33	0.404	-
P35	-	0.141
P36	-	0.055
P37	0.991	0.474
P38	0.699	0.181
P39	2.200	0.768
P41	1.010	0.363

Compound	100 mV IC_{50} (μM)	80 mV IC_{50} (μM)
P42	no effect	1.840
P43	2.375	0.279
P44	2.600	0.456
P45	10.000	0.833
P46	4.370	0.603
P47	1.436	0.464
P48	1.182	0.395
P49	2.700	0.835
P50	1.000	1.000

[0099] Again, the substitution pattern has a dramatic impact on the IC_{50} value.

Example 9

Activity of Invention Compounds in Formalin-Induced Pain Model

[0100] The effects of intrathecally delivered compounds of the invention on the rat formalin model were measured. The compounds were reconstituted to stock solutions of approximately 10 mg/ml in propylene glycol. Eight Holtsman male rats of 275-375 g size were randomly selected per test compound.

[0101] The following study groups were used, with test compounds, vehicle control (propylene glycol) and saline delivered intraperitoneally (IP):

Table 6: Formalin Model Dose Groups

Test/Control	Dose	Route	Rats per group
Compound	30 mg/kg	IP	6
Propylene glycol	N/A	IP	4
Saline	N/A	IP	7

N/A = Not Applicable

[0102] Prior to initiation of drug delivery baseline behavioral and testing data were taken. At selected times after infusion of the test compound or control these data were again collected.

[0103] On the morning of testing, a small metal band (0.5 g) was loosely placed around the right hind paw. The rat was placed in a cylindrical Plexiglas chamber for adaptation a minimum of 30 minutes. Test compound or vehicle control was administered 10 minutes prior to formalin injection (50 µl of 5% formalin) into the dorsal surface of the right hindpaw of the rat. The animal was then placed into the chamber of the automated formalin apparatus where movement of the formalin injected paw was monitored and the number of paw flinches tallied by minute

over the next 60 minutes. (See Malmberg, A. M., and Yaksh, T. L., *Anesthesiology* (1993) 79:270-281.)

[0104] Results are presented as Maximum Possible Effect ± SEM, where saline control = 100%.

Table 7: Efficacy of Invention Compounds in Formalin-Induced Pain Model

Compound	Phase I	Phase II	Phase IIA
P2	57±14	67±10	61±11
P3	89±8	79±4	85±5
P7	56±12	67±6	61±11
P8	78±5	70±15	57±18
P18	73±17	84±12	78±13
P29	78±17	70±10	61±9
P35	78±8	67±8	52±11
P36	62±14	60±10	42±9
P47	60±7	55±8	54±9
P48	76±13	65±11	66±14
P50	60±7	63±10	63±13